ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

WATER INFRASTRUCTURE FINANCE AUTHORITY OF ARIZONA

ARIZONA ARSENIC MASTER PLAN

PART 3 - COMPLIANCE OPTIONS

Final Report

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SECTION 1 - INTRODUCTION

1.0 BACKGROUND

This report presents the findings of the Compliance Options evaluations that were conducted as part of the Arizona Arsenic Master Plan. While the information presented in this report will be useful for all public water systems impact by arsenic in Arizona, it focuses on characterizing systems serving fewer than 10,000 persons and developing costs for funding mitigation projects for those impacted small systems. The impacted utilities are generally simple groundwater systems with wells, storage tanks, and hydropneumatic control systems. Further, of the systems impacted by the arsenic MCL in Arizona, 60% are in the size range of 25-500 persons served. To assist these systems in developing and implementing compliance options ADEQ, earlier in 2002, initiated the Arsenic Master Plan (AMP), which included workgroups for overview, funding, compliance options, and technical assistance. Each of these workgroups has developed a document that summarizes the findings of their activities and meetings; these summary documents will be integrated into the final overall AMP document issued by ADEQ.

Based on ADEQ records, it is estimated that almost 400 water systems serving less than 10,000 persons will be impacted by an arsenic standard of 10 ppb. The breakdown of these systems by size range and type (community water systems [CWS] and non-transient, non community water systems [NTNCWS]) is shown in Table 1.1.

Table 1.1: Impacted Small Systems by Size in Arizona

System Size	Type		Total	% of Total Impacted Systems
	CWS	NTNCWS		
25-500	134	40	174	60.6
501-3,300	67	17	84	29.3
3,301-10,000	24	5	29	10.1
	225	62	287	

The majority of these systems serve fewer than 500 persons. Providing technical assistance to these systems in terms of planning, technology evaluation, cost impacts, and operation and maintenance impacts is a vital component to ensure continued operation of these systems. Previous estimated combined capital and O&M costs for these 400 impacted systems to comply with an MCL of 10 ppb range from $22.2 million annually (EPA estimate) to $65.5 million annually (Awwa estimate). These estimates were based on similar unit cost curves from credible industry sources but assumptions regarding the treatment technologies utilized and the support facilities necessary varied significantly, causing the great disparity in estimated costs. As a result, there were no accurate estimates of treatment technologies or costs for small Arizona water systems to comply with a revised arsenic standard. The information presented in this report would bridge this information gap and provide WIFA and impacted water systems with the necessary information for facility planning and funding.

1.1 OBJECTIVES

The objectives of this project include:

- Characterizing the water quality and infrastructure of the impacted water systems.
- Identifying cost-effective technologies that can be implemented at these small water systems.
- Developing an Arizona-specific cost model for these favorable technologies.
- Determining capital and annual O&M costs for the impacted utilities for each POE
- Identifying the optimal means of complying with the future MCL for each impacted POE.
- Developing "boilerplate" facility configurations to assist water systems and ADEQ with the regulatory approval process during the design phase.

Identifying follow-up monitoring requirements to fill existing data gaps and determining future bench and pilot testing needs are also important objectives of the Arizona AMP. These activities will be required prior to allocation of final funds and final design of facilities.

Additionally, developing guidance on alternate compliance methods such as Point-of-Use (POU) devices and non-treatment options (blending and well modifications) is an objective of the Compliance Options document. These guidance documents are included as appendices in the Final Report. A web-based decision analysis tool to assist water systems in technology evaluation and selection for arsenic removal has been developed and will be posted on the ADEQ Home Page for use by water systems and the general public. A description of the decision analysis tool and the format is included in this report.

The recommendations from this study will focus on identifying uniform design criteria, infrastructure needs, operational and water quality considerations, and funding needs.

1.2 DOCUMENT ORGANIZATION AND STRUCTURE

The Compliance Options document has been has been divided into six sections, as discussed below.

1.2.1 Section 2 - Impacted Water Systems

Section 2 presents an accurate list of impacted water systems and an understanding of their physical infrastructure. This information is necessary to utilize the cost models and develop treatment costs for favorable treatment options.

The information presented in Section 2 was obtained from ADEQ's database and was used to determine impacted utilities and the number of wells requiring treatment. A written survey was distributed by ADEQ to over 200 water systems to obtain additional information regarding the physical infrastructure, site constraints, and residuals disposal alternatives. A very high response rate (greater than 60%) was obtained from this survey. Water quality and production data were also requested to supplement ADEQ's database information. The results of the survey are utilized throughout this report in developing treatment options and costs.

1.2.2 Section 3 - Water Quality Data Assessment

This section presents the findings of the inorganic contaminant data review that was performed. Inorganic contaminant data from 1993 - 2001, along with data for silica, phosphate, pH, temperature, and chlorine residual were evaluated. Data from ADEQ's drinking water database along with information from ADEQ's groundwater monitoring data base was used to perform this evaluation.

Since phosphorus and silica data are limited, eight general water quality profiles were developed utilizing arsenic, fluoride, and pH data. These profiles will assist with technology evaluation, selection, and assessing treatment efficiency. The impacted POEs identified under Task 1 were each categorized to a particular water quality profile. Future monitoring needs were also identified to address data gaps.

1.2.3 Section 4 - Treatment Alternatives and Cost Models

Arsenic treatment options for small groundwater systems in remote areas are limited when compared to large ground or surface water systems. The issues associated with residuals handling and disposal are more complex than the primary treatment issues. Many of the sites may be located within residential neighborhoods where land for additional facilities may not be available. Strategies that minimize chemical treatment and on-site handling of residuals are preferred, since operations will be unattended.

Three main categories of arsenic treatment technologies were considered for the impacted small systems in Arizona (as shown in Table 1.2). Several sub-options were also developed for each category, based on water quality, potential for partial stream treatment and level of redundancy required. As a result, 12 adsorption based cost models were developed with varying configuration options and media type. Technologies such as nanofiltration/reverse osmosis, electroidialysis reversal, activated alumina (AA) with on-site regeneration, and ion exchange (IX) (with and without brine recycle) were not considered due to brine disposal issues and hazardous waste considerations. Coagulation with microfiltration was not considered due to its high cost and level of complexity.

An overview of the treatment processes under consideration and preliminary design guidelines including generic equipment configurations and site layout options are included in Section 4. The layouts shall consider full-scale flow rates, optimal pressure vessel or module configuration, chemical feed requirements, hydraulic issues (flow splitting and need for equalization and booster pumping after treatment), controls, and operational flexibility. Report-style plan drawings that summarize the findings of this task are included for reference.

All cost models assume that arsenic is in the +5 or fully oxidized valence state (arsenate). It is assumed that if arsenite (+3) is present, it will be oxidized using chlorine or another simple pretreatment setup. For treatment systems to work efficiently, arsenic must be present in the +5 state.

Table 1.2: Arsenic Removal Technologies for AMP

Technology	Key Implementation Factors
Coagulation with Filtration – pressurized granular media filtration process with pretreatment. Arsenic +5 removed effectively as iron particles attach to arsenic for subsequent removal by granular media or microfilter. Backwash water is 5-8% of plant flow and must be recovered on-site. Ferric chloride dose is 5 mg/L.	On-site backwash treatment is also required. Solid non-hazardous residual generated. Ferric chloride storage and feed systems required. Hazardous waste issues not anticipated. Complete demineralization does not occur. Adjustment of pH may be required if >8.
Granular Iron Media - A fixed-bed adsorption process that utilizes granulated ferric hydroxide (GFH) or Sorb-33 to remove As +5. The adsorptive capacity of GFH is several times greater than Fe-AA, as confirmed in recent tests conducted in Arizona. System design is similar to Fe-AA.	Interference from phosphate and silica is significant. pH impacts performance >8 but not as significantly as Fe-AA. Media used on a throw-away basis. Hazardous wastes not generated.
Iron Modified AA Media – adsorptive process where arsenic +5 is removed with AA or iron particles coated with iron oxides. Lab tests have shown effective removal rates and the potential for long run lengths. pH adjustment to 6.5 is required.	Additional pilot test data required to verify performance under local conditions. Some media specifications may be proprietary. Silica interference is significant. Media used on a throw-away basis. Hazardous wastes not generated.

The applicability of the new cost models to the impacted water systems in Arizona was performed, using water quality data, site constraints, and costs. The water quality matrix developed in Task 2 was utilized to select appropriate technologies for each system size and water quality profile. A list that correlates the appropriate treatment technologies for each general type of water quality profile that impacts arsenic treatment was prepared.

Costs for point of use devices options were also developed, for those very small systems serving fewer than 90 connections. The technology assessment will serve as a screening tool and includes preliminary design criteria, capital and operating and maintenance costs, residual handling issues, water loss, residuals, and water quality considerations for all three technologies (Fe-AA, CF, and Granular Iron Media). Where appropriate, concurrent treatment needs for chromium, iron, and manganese will also be identified. The Web-based decision tree will allow any user to perform this technology and cost assessment through a series of input questions and answers block.

1.2.4 Section 5 - Cost Assessment

This section also presents the capital and O&M costs for the two preferred technologies for each impacted water system using the Arizona specific cost model. The cost estimates were based on pre-design level unit quantities, with line item costs for each major piece of treatment and ancillary equipment for the preferred technologies.

Although information from the existing ADEQ database and survey was sufficient to develop estimates for arsenic mitigation costs for most of the impacted systems, costs for approximately 20% of the impacted systems were developed using broad-based assumptions due to insufficient data. To develop accurate costs for these systems with insufficient data, assistance from the ADEQ workgroup (AMP stakeholders) will be required to obtain the necessary physical facility configuration information. For planning purposes, it was assumed that wellhead or central treatment was utilized for each impacted water system. Systems may elect to use POU devices or non-treatment options, but these evaluations are very site specific and it is not practical to assess their feasibility at the master planning stage due to the large number of systems.

1.2.5 Appendices

1.2.5.1 Appendix A2 - Criteria for Non-Treatment Options

This section provides criteria for development and evaluation of non-treatment options to achieve compliance with the arsenic MCL. These include well bore modifications where selected intervals of the aquifer are sealed to prevent intrusion of high arsenic water into the potable water supply. This approach has been implemented for wells in the Phoenix, Arizona area with mixed success for arsenic. Blending with low-arsenic surface water and/or other groundwater supplies may also be considered as an alternative to treatment since significant capital and O&M costs savings are possible for some utilities. An important aspect of blending is that the wells will have to be operated with a higher degree of control to ensure proper blending. Wells with higher levels of arsenic blended with wells having lower levels of arsenic cannot be operated unless the lower arsenic well is operating. Such criteria along with all other constraints and necessary regulatory approvals will be discussed. Decision analysis tools and costs will be developed to assist utilities in making decisions regarding these non-treatment options.

1.2.5.2 Criteria for Point of Use Devices

ADEQ is developing criteria for use of POU/POE systems as an alternative to centralized treatment with stakeholder input, considering factors such as process reliability, public perception, liability and control. Water quality criteria that may limit the performance of POU/POE systems will be assessed. Guidance will be developed for the installation, maintenance, management, monitoring and regulatory oversight of POU/POE systems for arsenic treatment. Other ongoing documents that will also assist small systems with POU criteria include AwwaRF Project 2730, "Point-of-Use Implementation Feasibility Study for Arsenic Removal" and EPA guidance information.

The required procedures for implementation, operation, maintenance, and monitoring of POU/POE systems will be finalized by ADEQ during 2003.

1.2.5.3 Web Based Decision Analysis Tool

Smaller systems with less operator experience and fewer economical resources will likely choose technologies which are easy to operate and require less chemical addition, such as disposable adsorptive media (e.g., iron-enhanced activated alumina (Fe-AA) or granular iron media) processes. For many small systems, the disposable adsorption media may be the least cost alternative for arsenic removal. Choosing an adsorptive media process with no regeneration eliminates the need for the utility to handle toxic chemicals and hazardous wastes that are used/generated by the other treatment processes. Removal of arsenic by disposable adsorption media can be accomplished in several different ways (e.g., use of single column vs. two columns, split-stream vs. full flow treatment). Based on discussions with the ADEQ staff/stakeholders, the following list of alternatives were identified for arsenic removal for small utilities:

- Fe-AA adsorption with single column and direct pumping into the distribution system
- Fe-AA adsorption with single column, pumping into a storage tank and re-pumping into the distribution system
- Granular iron media adsorption with single column and direct pumping into the distribution system
- Granular iron media adsorption with single column, pumping into a storage tank and re-pumping into the distribution system
- Fe-AA adsorption with two columns in series, full-flow is treated, direct pumping into the distribution system
- Fe-AA adsorption with two columns in series, full flow is treated, pumping into existing storage tank and re-pumping into the distribution system
- Fe-AA adsorption with two columns in series, partial stream is treated, pumping into existing storage tank and re-pumping into the distribution system
- Fe-AA adsorption with two columns in series, partial stream is treated, pumping into new storage tank and re-pumping into the distribution system
- Granular iron media adsorption with two columns in series, full flow is treated, direct pumping into the distribution system
- Granular iron media adsorption with two columns in series, full flow is treated, pumping into existing storage tank and re-pumping into the distribution system
- Granular iron media adsorption with two columns in series, partial stream is treated, pumping into existing storage tank and re-pumping into the distribution system
- Granular iron media adsorption with two columns in series, partial stream is treated, pumping into new storage tank and re-pumping into the distribution system
- Coagulation with granular media filtration
- Point-of-use (POU) treatment by adsorption
- POU treatment by reverse osmosis

To assist small utilities in selecting the least-cost and most feasible alternatives from the above list, a web-based, interactive decision tree program has been developed. This program will assist in screening and selecting preferred arsenic removal technologies for the impacted wells that do not have an existing treatment (other than disinfection alone) in place. The web tool is equipped with costs and other pertinent information on the seventeen different treatment alternatives. This tool seeks system information such as flow, raw water quality, site constraints and cost factors in a user-friendly input form. An outline of the input form and the parameters that are included in the input form are shown in Table 1.3.

Based on the information entered, the tools estimates and outputs:

- Planning-level installation and operation costs for each treatment technology
- Qualities and quantities of residuals that would be generated
- Land required for installing new treatment systems and
- Water quality flags, such as interfering ions from source water or treated water and potential distribution system corrosion issues

The output form layout indicating the types of output is shown in Table 1.4.

The web tool identifies the feasible alternatives based on water quality and site constraints. The treatment and operation costs that will be outputted by the tool are site-specific and account for reduction in adsorption capacities from the presence of interfering ions (e.g., silica, phosphate) in the source water. The tool also ranks the feasible technologies based on costs, from least-cost to the highest cost alternative. With this tool, the user can analyze various "what if" scenarios to evaluate alternative ways to address arsenic removal from their impacted groundwater sources. Impacted systems can refer to ADEQ website (www.adeq.state.az.us) for information on the web based tool.

In addition to the input and output forms, the decision analysis tool will also be provided with a "Help" file to assist users with navigation and to let them know where to get additional information. The outputs from this tool should be used only for planning purposes. The recommendations of the tool have to be tested prior to implementation.

Table 1.3: Outline of the Input Form for the Web Tool

INPUT FORM

System Parameters	***Input Type***
Well capacity (gpm)	Value between 0-1400
Annual average flow (gpm)	Value between 0-1400

Water Quality	***Input Type***
Influent arsenic (µg/L)	Value between 0-50
Treated water arsenic goal (µg/L)	Value between 0-10
Raw water pH	Value between 5-10
Raw water fluoride (mg/L)	Value between 0-10
Raw water silica (mg/L)	Value between 0-100
Raw water phosphate (mg/L)	Value between 0-10
Raw water iron (mg/L)	Value between 0-10
Raw water manganese (mg/L)	Value between 0-10
Raw water sulfate (mg/L)	Value between 0-200
Raw water TDS (mg/L)	Value between 0-2000
Raw water alkalinity (mg/L)	Value between 0-500

Site Constraints	***Input Type***
Is this well the primary source of water?	Yes/no
Are you interested in a split-stream treatment?	Yes/no
Is there any system storage available?	Available/not available
Is there any clearwell or treated water storage?	Available/not available
Will the well pump be able to handle an additional head of 20 feet?	Yes/no
How much land is available at the well site (square feet)?	Numerical value
What is the cost for purchasing additional land ($/acre)?	Numerical value
Are you interested in under-the-sink/point-of-use (POU) treatment?	Yes/no
Is there a sewer/storm drain nearby?	Yes/no

Cost Inputs	***Input Type***
Are you willing to pay the engineering costs?	Yes/no
What is the bonding interest rate (%)?	Value between 0-10
What is the payback period for bonds (years) ?	Value between 0-30
Current ENR Construction Cost Index?	Numerical value
Current ENR Skilled Labor Cost Index?	Numerical value

Table 1.4: Outline of the Output Format for the Web Tool

OUTPUT FORM

Technologies	**Feasible or Not Feasible**	**Capital Cost ($)**	**O&M Costs ($/yr)**	**Annualized Total Cost ($/year)**	**Total Cost ($/kgal)**	**Rank of Technology by Cost**
Fe-AA with Single Column and Direct Pumping into Distribution System						
Fe-AA with Single Column, Pumping into a Storage Tank and Re-pumping into Distribution System						
Granular Iron Media with Single Column and Direct Pumping into Distribution System						
Granular Iron Media with Single Column, Pumping into a Storage Tank and Re-pumping into Distribution System						
Fe-AA with Two Columns in Series, Full Flow Treated, Direct Pumping into Distribution System						
Fe-AA with Two Columns in Series, Full Flow Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System						
Fe-AA with Two Columns in Series, Partial Stream Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System						
Fe-AA with Two Columns in Series, Partial Stream Treated, Pumping into New Storage Tank and Re-pumping into Distribution System						
Fe-AA with Two Columns in Series, Partial Stream Treated, Direct Pumping into Distribution System without Any Storage						
Granular Iron Media with Two Columns in Series, Full Flow Treated, Direct Pumping into Distribution System						
Granular Iron Media with Two Columns in Series, Full Flow Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System						
Granular Iron Media with Two Columns in Series, Partial Stream Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System						
Granular Iron Media with Two Columns in Series, Partial Stream Treated, Pumping into New Storage Tank and Re-pumping into Distribution System						
Granular Iron Media with Two Columns in Series, Partial Stream Treated, Direct Pumping into Distribution System without Any Storage						
Coagulation, High-Rate Media Filtration						
Point-of-Use Treatment by Adsorption						
Point-of-Use Treatment by Reverse Osmosis						

Residuals Quantities/Characteristics and Water Quality Warnings	**Solids**	**Liquids**	**Water Quality Flags - Interfering Ions and Treated Water Quality Impact**	
Fe-AA Adsorption				
Granular Iron Media Adsorption				
Coagulation, High-Rate Media Filtration				
POU Treatment				

Land Requirement Estimations	**Available Land (acres)**	**Additional Land Required (acres)**	**Cost for Purchasing Additional Land ($)**
For all the feasible technologies listed above			
Fe-AA with Single Column and Direct Pumping into Distribution System			
Fe-AA with Single Column, Pumping into a Storage Tank and Re-pumping into Distribution System			
Granular Iron Media with Single Column and Direct Pumping into Distribution System			
Granular Iron Media with Single Column, Pumping into a Storage Tank and Re-pumping into Distribution System			
Fe-AA with Two Columns in Series, Full Flow Treated, Direct Pumping into Distribution System			
Fe-AA with Two Columns in Series, Full Flow Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System			
Fe-AA with Two Columns in Series, Partial Stream Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System			
Fe-AA with Two Columns in Series, Partial Stream Treated, Pumping into New Storage Tank and Re-pumping into Distribution System			
Fe-AA with Two Columns in Series, Partial Stream Treated, Direct Pumping into Distribution System without Any Storage			
Granular Iron Media with Two Columns in Series, Full Flow Treated, Direct Pumping into Distribution System			
Granular Iron Media with Two Columns in Series, Full Flow Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System			
Granular Iron Media with Two Columns in Series, Partial Stream Treated, Pumping into Existing Storage Tank and Re-pumping into Distribution System			
Granular Iron Media with Two Columns in Series, Partial Stream Treated, Pumping into New Storage Tank and Re-pumping into Distribution System			
Granular Iron Media with Two Columns in Series, Partial Stream Treated, Direct Pumping into Distribution System without Any Storage			
Coagulation, High-Rate Media Filtration			
Point-of-Use Treatment by Adsorption	NA	NA	NA
Point-of-Use Treatment by Reverse Osmosis	NA	NA	NA